SATELLITE TRACKING OF BAR-HEADED GEESE *ANSER INDICUS* WINTERING IN UTTAR PRADESH, INDIA

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In 2010, 4 Bar-headed Geese were captured and fitted with satellite transmitters at Sur Sarovar Bird Sanctuary in Uttar Pradesh, India, to examine their migration and distribution. The individuals fitted with Platform Transmitter Terminal (PTT) 99072, 99073, 99075 and 99076 spent a total of 30 days, 16 days, 36 days and 23 days respectively, in their wintering range after deployment of PTTs. During wintering, Goose 99073 and 99076 ranged within an area of 48.65 sq. km and 124.37 sq. km. However, Goose 99072 and 99075 ranged within an area of 106.76 sq. km and 149.84 sq. km. They migrated towards their breeding grounds between March 25, and April 12, 2010. During their migration, they flew over the Himalaya, a significant barrier to migration for most birds. The Geese equipped with PTT 99072, 99073, 99075 and 99076 covered a total distance of 877 km, 1,005 km, 807 km and 1,305 km respectively. All 4 birds flew to the breeding areas on the Tibetan Plateau, and stayed there for a period of 153-222 days. Three Geese (99072, 99073 and 99076) made a stopover over Xizang province for 1-2 days. However, Goose 99075 directly flew to the breeding ground. Goose 99073 moved within an area of 3,155 sq. km and used three focal areas of 438 sq. km, 457 sq. km and 510 sq. km. Among the four geese, Goose 99076 established itself in the northernmost part. It moved over an area of 10,866.77 sq. km and used two focal areas of 1,168 and 3,368 sq. km size intensively. Goose 99072 moved over an area of 5,263 sq. km and used four focal areas of 75.19 sq. km, 389.9 sq. km, 253.25 sq. km and 236.21 sq. km. Goose 99075 ranged within an area of 13,932 sq. km and intensively moved in three focal areas of 690.18 sq. km, 2,214.68 sq. km and 852.21 sq. km. Geese 99076, 99072, 99075 and 99073 ascended to 5,520, 5,090, 4,790 and 4,920 m above msl respectively, while crossing the Himalaya.

Key words: Bar-headed Geese, Sur Sarovar, migration, distribution

INTRODUCTION

Large numbers of species undertake seasonal migration from their breeding grounds to their wintering grounds each year. This is particularly known in birds, some of which show trans-continental migration involving thousands of kilometres each year. A massive amount of ringing data is collected by many people, including volunteers and professionals. These data help in drawing the distribution boundary of a species and also to track general migration routes. However, satellite tracking helps in identification of precise migration path. It could be linked further to studies on outbreak of avian-borne diseases and migration movement.

As avian influenza emerges and spreads globally, infecting humans along the way, it is necessary to detect an outbreak of the virus as quick as possible. In the last couple of years, several cases have been reported where human beings became infected due to contact with infected birds. So far, 337 cases of human H5N1 have been reported from 59 countries (Williams *et al.* 2008). The main species that serve as reservoirs for spreading viruses are aquatic wild birds, mainly from families of Anseriformes and Charadriiformes such as ducks, geese, swans, gulls, terns and shorebirds (Suarez 2000; Swayne and Suarez 2000). Several authorities, including the more recent Normile (2006), reported that migratory species have the capacity to spread the virus at the time of migration. However, this hypothesis is not accepted universally (Kou *et al.* 2005).

In 2005, avian influenza outbreak was reported from China, at Qinghai lake and the Xinjiang province, and HPAI H5N1 virus was isolated from oropharyngeal and cloacal swabs of carcasses of Bar-headed Geese *Anser indicus*, indicating that H5N1 virus was the cause of death in these birds. The Bar-headed Goose is thus a high-risk species as far as spread of H5N1 is concerned. Therefore, because of these alarming concerns, we selected the Bar-headed Goose for satellite telemetry study during our project "Migratory Movements of Waterbirds through Uttar Pradesh and the Surveillance of Avian Diseases". Migration of Bar-headed Goose across the Himalaya, connectivity of its wintering areas

in Keoladeo National Park, Bharatpur, India, and Royal Chitwan National Park, Nepal, and breeding grounds in China and Mongolia have recently been investigated by several scientists by using satellite telemetry (Javed *et al.* 2000; Takekawa *et al.* 2009; Gilbert *et al.* 2011).

The Bar-headed Goose is a species of high altitude wetlands with a global population of <60,000 individuals in the wild (Miyabayashi and Mundkur 1999; Wetlands International 2006; Takekawa *et al.* 2009). Perennou *et al.* (1994) estimated less than 50,000 Bar-headed Goose in the world and the number is probably increasing. The current global population of the species is estimated at *c.* 52,000-60,000 mature individuals and a range (breeding and winter) of 2,370,000 sq. km (BirdLife International 2010). The species is one of the abundant waterbirds, in no immediate danger, and is not on the Threatened list of BirdLife International and IUCN 2010. However, Koppen *et al.* (2010) reported that the population has been adversely affected in recent decades due to unsustainable levels of egg collection, hunting by humans and habitat destruction.

Bar-headed Geese breed on or near large wetlands on high plateaux within a fragmented range from Kyrgyzstan to central China, and as far north as Mongolia (Wurdinger 2005; Takekawa *et al.* 2009; Koppen *et al.* 2010). Bishop *et al.* (1997) reported that more than 25% of the world population winters on the southern Tibetan-Qinghai Plateau. India is a wintering ground for another 25-50% of the population (Javed *et al.* 2000). The total number of breeding pairs in countries, namely Uzbekistan, Tadjikistan and Kyrgyztan will not be more than 150-200 (van der Ven 1997). It is quite common across northern India and the Gangetic Plain (including the Nepal *terai*) to Assam (Ali and Ripley 1987). More than 20,000 individuals of this species have been recorded from a single site, Pong Dam Sanctuary, Himachal Pradesh (Li *et al.* 2009). In Uttar Pradesh, it is found on all large marshes and rivers, especially where some protection is afforded. It has been reported from Sheikha Jheel, Aama Khera and Ratika-Nagla, all in Aligarh district, Patna Bird Sanctuary in Etah district, Lakh-Bahosi in Farrukhabad district, Samaspur in Raebareli district, Saman in Mainpuri district, Nawabganj in Unnao district, Narora Reservoir and on the banks of the River Ganga in Bulandshahr and Badaun districts, and numerous other wetlands (Rahmani 1992; Rahmani and Arora 1992; Rahmani and Islam 2008; Rahmani *et al.* 2010). The population has suffered some reduction in numbers due to loss of wetlands in the wintering areas (Foote *et al.* 1996), habitat alteration in portions of their breeding range (Wang *et al.* 2008; Xu *et al.* 2008) and susceptibility to emerging infectious diseases, such as highly pathogenic avian influenza H5N1 (Chen *et al.* 2005; Brown *et al.* 2008). The species is believed to hold a unique physiological feature for flying high (Ward *et al.* 2002; Scott and Milsom 2007; Lee *et al.* 2008).

The possibilities of studying bird migration have increased with the use of satellite tracking. Earlier research work related to bird migration was mainly based on ring recovery data. Satellite tracking offers more detailed information about animal migration routes, wintering ground, home range, behaviour and habitat selection (Seegar *et al.* 1996; Bobek *et al.* 2008). Recently, many birds species such as cranes (Kanai *et al.* 2002), Bar-tailed Godwit (Gill Jr. *et al.* 2008), pelicans (Izhaki *et al.* 2002), raptors (Hake *et al.* 2001), White Stork (Berthold *et al.* 2001, 2002) and Black Stork (Bobek *et al.* 2008) have been satellite-tracked successfully during migration. These methods have provided an easier and faster means of capturing information about migration than ever before. The data available from the Platform Transmitter Terminal (PTT) and radar provide a formidable challenge to understand the spatio-temporal distribution pattern, habitat use and flight locations of migrating birds over large areas.

The focus of our study was to provide information on movement patterns of Bar-headed Goose from Uttar Pradesh, India to the Tibetan Plateau. Our objectives were: 1) Identify areas used as wintering, breeding and stopover sites; 2) Estimate distribution area of each bird at wintering and breeding site; and 3) Determine the time of migration.

STUDY AREA

The floodplain wetlands of the Gangetic Plains of Uttar Pradesh host a multitude of waterfowl each year, both resident and migrant. Bar-headed Geese were captured at Sur Sarovar Bird Sanctuary (27° 00' N; 77° 45' E) near Agra. It is an Important Bird Area (IBA) identified by the Bombay Natural History Society and BirdLife International (Islam and Rahmani 2004) and a potential Ramsar Site (Islam and Rahmani 2008). Sur Sarovar is located on the Agra-Delhi National Highway NH2, about 20 km from Agra, east of the road. It is a water reservoir spread over 7.83 sq. km area, owned by the Irrigation Department of Uttar Pradesh, but now managed by the Forest Department.

The Tibetan Plateau is the highest and largest plateau in Central Asia, covering most of the Tibet Autonomous Region and Qinghai, in addition to smaller portions of western Sichuan, southwestern Gansu, and northern Yunnan in western China and Ladakh in India. It covers an area of 2.5 million sq. km. The Tibetan Plateau has various complex landforms, such as high and steep mountains, deep valleys, glaciers, and bare rocks, with an average elevation of 4,500 above msl.

METHODOLOGY

In 2010, 5 birds were equipped with satellite PTTs at Sur Sarovar Bird Sanctuary and Sheikha Jheel in Uttar Pradesh, India. Of these 4 were Bar-headed Goose and 1 was Gadwall. The PTTs were supported with batteries having a maximum life span of six months. The PTTs were programmed by experts at Telonics Inc. in such a way that they were switched on during the periods when the maximum number of satellites passed over the bird activity areas.

The individual Identification Numbers (IN) of the PTTs, provided by ARGOS France, are mentioned in Table 1. ARGOS PTT Nos. 99072 and 99075 were deployed on two Bar-headed Geese in the Sur Sarovar Bird Sanctuary on March 7 and subsequently two more PTTs, Nos. 99073 and 99076, were fastened to two other individuals of the same species on March 9, 2010, at the same site. One of the five PTTs was fastened to a Gadwall at Sheikha Jheel, an IBA located 20 km away from Aligarh on the Aligarh-Panethi-Jalali road. The Geese as well as Gadwall were captured by a team of professional trappers working with the Bombay Natural History Society (BNHS) using nooses when the birds were about to return to their breeding grounds. The PTTs were attached to the Bar-headed Geese and Gadwall as backpacks using Teflon ribbon harness. The birds were weighed and swabbed orally and cloacally to get samples for investigation of avian influenza, and were also marked with metal rings provided by the BNHS. Each PTT weighed 29 gm, which is *c.* 1% of the total body weight of Bar-headed Goose and 3.5% of the total body weight of Gadwall.

The transmitter signals were intercepted by polar orbit satellites (NOAA) and received at the headquarters of the American-French Company ARGOS. Location data is categorised into different classes such as Z, B, A, 0, 1, 2, 3 to get the measurement of accuracy. It is reported that the system does not calculate the error for Z, B, A due to inadequate reception frequency (Ueta 2000). The data were filtered to exclude the inaccurate points found away from the nearest tracking times and locations. A total of 4,338 locations was obtained and 2,328 of them were used to construct the migration tracks of four individuals. For more information about locations of the tracked geese, see Table 2. The tracks were constructed on the basis of directional movement recorded away from the wintering site. The total length of the tracks was calculated to estimate travel distance between their wintering and breeding grounds.

Maps of migratory routes were generated using the GIS software (ArcGIS and ArcView) with animal movement analysis extensions by one of the authors (MK). Movement areas of each bird in their wintering and breeding grounds were estimated using the minimum convex polygon method.

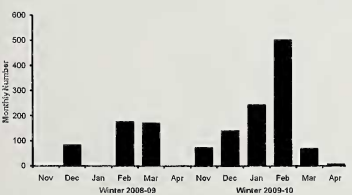

Fig. 1: Population of Bar-headed Geese at Sur Sarovar Bird Sanctuary, Agra, India (November 2008-April 2010)

RESULTS

All marked geese remained in their wintering grounds after they were fitted with the PTTs for a duration ranging from a minimum of 16 to a maximum of 36 days (Table 3). During wintering period at Sur Sarovar the marked geese moved extensively within as well as outside the Sanctuary. The total number of points located within the Sur Sarovar Bird Sanctuary were 13.22%, 5.13% and 4.17% for Geese 99072, 99075 and 99076 respectively. However, Goose 99073 was not located at any point of time within the Sanctuary.

The duration of functioning of ARGOS PTTs was from 6½ months (ID 99072) to nearly nine months (ID 99075) (Table 2). Altogether 4,338 locations were received from CLS ARGOS France for all individuals of Bar-headed Goose fitted with ARGOS transmitters. For analysis, we used 2,328 (54%) locations belonging to 0, 1, 2, 3 categories of location of ARGOS, which have higher accuracy (Table 2). The remaining 46% of location categories (i.e., A, B and Z) which have low accuracy were excluded from data analysis. The total number of locations used in data analysis for the geese with IDs 99072, 99073, 99075, and 99076 were 542, 610, 719 and 457 respectively, for the above-mentioned location classes.

Wintering Areas

During our fortnightly field visits to the Sanctuary in winters of 2008-2009 and 2009-2010, we recorded a maximum of 502 Bar-headed Geese in February 2010 (Fig. 1). As indicated by ground observations and point locations provided by ARGOS, they moved around the Sanctuary extensively, using crop fields and islands of River Yamuna for foraging and resting. During our fortnightly field visits to the Sanctuary we noticed that more than half of the population of Bar-headed Geese would spread out into the

Table 1: Spring migration of four Bar-headed Geese tracked by satellite telemetry from India to Tibetan Plateau

Species (ARGOS ID)	Site (Date of deployment of PTT)	Coordinates	Ring No.	Start of migration (Site)	Arrival at stopover site (DoDSO)	Arrival at breeding ground	Max altitude during flight (in metres)	No. of travelling days between W & B	Total distance* (Avg. distance travelled/day) (in km)	DoMBG & DoAWG
Bar-headed Goose (99072)	Sur Sarovar, Agra (Mar 7, 2010)	27° 34' 60" N 78° 45' 60" E	3906 K	Apr 6, 2010 Catchment of Yamuna	Apr 7 (Apr 14)	Apr 15	5,090	9	877 (97.4)	—
Bar-headed Goose (99075)	Sur Sarovar, Agra (Mar 7, 2010)	27° 34' 60" N 78° 45' 60" E	3907 K	Apr 12, 2010 Catchment of Yamuna	—	Apr 16	4,790	4	1,005 (251.3)	Oct 26 & Nov 2
Bar-headed Goose (99073)	Sur Sarovar, Agra (Mar 9, 2010)	27° 34' 60" N 78° 45' 60" E	3911 K	Mar 25, 2010 Catchment of Yamuna	Mar 27 (Mar 31)	Apr 3	4,920	9	807 (89.7)	—
Bar-headed Goose (99076)	Sur Sarovar, Agra (Mar 9, 2010)	27° 34' 60" N 78° 45' 60" E	3912 K	Apr 1, 2010 Yamuna riverbed	Apr 4 (Apr 12)	Apr 13	5,520	12	1,305 (108.8)	—

* refers to the distance travelled during spring migration

DoDSO=date of departure from stopover site, W=wintering ground, B=breeding ground, DoMBG=date of migration from breeding ground, DoAWG=date of arrival at wintering ground

surrounding areas, especially the islands and the catchment area of the River Yamuna flowing close to the Sanctuary. During the day, the geese were also sighted in crop fields, but most would return to the Sanctuary in the evening.

The geese spent a minimum of 16 days (ID 99073) to a maximum of 36 days (ID 99075) in their wintering range after the PTTs were fastened to them (Table 3). The two other individuals remained in their wintering areas for 30 days (ID 99072) and 23 days (ID 99076). The total number of locations received for PTTs from CLS ARGOS for the duration the geese remained in their wintering range was 369, and during this period they ranged from a minimum area of 49 sq. km (ID 99073) to a maximum of 150 sq. km (ID 99075). Geese 99072 and 99076 ranged in an area of 107 and 124 sq. km based on 121 and 72 locations respectively (Table 3 and Figs 3-7). One Bar-headed Goose (ID 99075) went twice around Keoladeo National Park, Bharatpur, but returned to Sur Sarovar in the evening on each occasion (Fig. 7). Goose 99073 travelled a minimum distance of 115.24 km, whereas goose 99075 covered a distance of 404.26 km in its wintering ground (Table 3). Goose 99072 and 99076 travelled 224 and 255 km respectively in their wintering ground before commencing spring migration to their breeding ground.

The overlap area between 99072-99075, 99075-99076, 99072-99073 and 99072-99076 was 25 sq. km, 14 sq. km, 22 sq. km and 1.6 sq. km respectively. However, area overlap among 99072-99073-99075 was 18 sq. km. The maximum overlap area was 31 sq. km shared by the four geese (Fig. 7).

Migratory routes and stopover sites

Bar-headed Geese fitted with PTTs started migrating back to their breeding grounds on March 25, 2010 (ID 99073) and the last (ID 99075) commenced migration on April 12 (Table 1). In the plains of north India, the geese tend to fly 100-200 m above ground but to cross Himalayas, they quickly ascend, sometimes reaching up to 5,600 m above msl (Fig. 2). As revealed by ARGOS locations, all PTT marked Bar-headed Geese started migration from Yamuna riverbed and its catchment area (Figs 3-6) and none from the Sanctuary.

Bar-headed Goose (ID 99073) started migration from the catchment area of the Yamuna on March 25 and reached a stopover site in a remote wilderness area in China in two days. It also halted around water bodies near Badaun, Bareilly and Shahjahanpur areas of Uttar Pradesh (Fig. 8). There were two locations of this individual near Dudhwa National Park on March 26, and it entered Nepal the same day. The bird

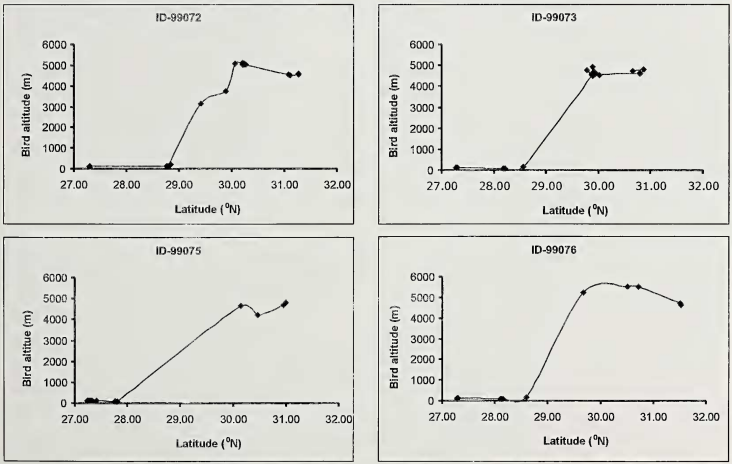

Fig. 2: Relationship between latitude and migration altitude for four satellite equipped Bar-headed Geese

flew up to maximum of 6,087 m above msl before reaching its breeding ground in China. It stayed at a stopover site (29° 53' 20.84" N; 83° 38' 16.32" E) for four days (Table 1) and based on 21 locations, it ranged in an area of 65 sq. km (Table 3). The goose reached its breeding ground in three days, covering a total distance of 807 km during migration (Table 1). The transmitter of this bird stopped functioning on September 20 (Table 2).

The Bar-headed Goose (ID 99076) started migration from the Yamuna riverbed on April 1 (Table 1) and halted near or on water bodies near Badaun, Bareilly, Pilibhit and Shahjahanpur (Fig. 8) for two to three days. The goose reached a stopover site (31° 29' 50.94" N; 83° 07' 48.14" E) in China on April 4 and remained there for 8 days (Table 1). Based on 23 locations, the individual moved within an area of 297 sq. km (Table 3). Among all marked geese, this individual settled in the northernmost area. During migration it crossed the Himalaya at an altitude more than 5,951 m above msl (Fig. 2) and covered the longest distance (1,305 km) among the four geese that were marked by us with ARGOS transmitters. Its transmitter stopped functioning on November 12 (Table 2) while proceeding on its winter migration from China and was last recorded through ARGOS location near China-Nepal border.

The Bar-headed Goose (ID 99072) left its wintering ground from the catchment area of Yamuna (Table 1) on April 6, first heading north-west, later it turned north-east. It used two stopover sites, first in Nepal for a few hours, and departed for the second stopover in China. After leaving Yamuna area, it also stayed around some ponds and water bodies near Badaun, Bareilly, Rampur, Shahjahanpur, Pilibhit and near Dudhwa National Park in Lakhimpur-Kheri before entering Nepal (Fig. 8). There were a few locations (n= 6) in the first stopover site in Nepal where it stayed for less than a day. However, there were 19 locations in the second stopover site (30° 13' 8.06" N; 83° 35' 34.7" E) in Tibet, based on which it was estimated to have moved over 30 sq. km area (Table 3). It reached the second stopover site in China in a day and used this area for seven days (Table 3). The bird flew at more than 5,979 m above msl (Fig. 2), and moved in the Indo-Nepal Himalayan range to reach its breeding ground, covering a total distance of 877 km during migration (Table 1). The transmitter of this bird stopped functioning on September 15, 2010 (Table 2).

The Bar-headed Goose (ID 99075) also commenced migration from the catchment area of River Yamuna. Among the four marked geese, it spent the maximum time (36 days) in its wintering area (Table 3) after the PTT was fixed to it. The bird started migration on April 12 (Table 1) when atmospheric temperature had reached 40 °C. Before flying back to its breeding ground it moved slowly around rivers and water bodies near Badaun, Bareilly and Udham Singh Nagar for 3 days (Fig. 8). From Uttarakhand, the bird entered Nepal near Dhangarhi (30° 27' 1.62" N; 81° 05' 40.79" E) and returned the same day to Uttarakhand state to an area located close to the boundary with Nepal. From Uttarakhand, it flew to its breeding ground at an altitude of 4,790 m above msl (Fig. 2) in the Himalayan range , covering a total distance of 1,005 km during migration. The PTT on this Bar-headed Goose (ID 99075) worked for the longest period of time. The bird started migrating from China on October 28, 2010 and reached Sur Sarovar, the same site it had visited in the winter of 2009-2010 (Fig. 9). It arrived at its wintering ground on November 2, 2010 (03:38 hrs) and was located around Keoladeo National Park, Bharatpur (27.24° N; 77.78° E) at 14:46 hrs on the same day. It covered a total distance of 1,239 km in 5 days while migrating towards its wintering ground. The goose flew above 4,790 m above msl while crossing over the Himalaya (Fig. 2). The PTT of this bird stopped functioning on November 24, 2010 (Table 2).

Table 2: Month-wise number of locations obtained from CLS ARGOS from March 7 to November 24, 2010, indicating different location classes

Bird ID No.	Date of first transmission	Number of Monthly locations									ARGOS Location class							Locations used in analysis	Total locations	Date of last transmission	Duration PTT's functioned
		M	A	M	J	J	A	S	O	N	0	1	2	3	A*	B*	Z*				
99072	7 Mar 2010	116	153	164	128	131	60	4	0	0	237	169	102	34	82	110	22	542	994	15 Sep 2010	193 days
90073	9 Mar 2010	104	136	130	138	132	108	67	0	0	264	247	71	28	94	84	27	610	984	20 Sep 2010	196 days
90075	7 Mar 2010	96	130	126	121	140	118	126	124	73	290	278	112	39	145	153	37	719	1351	24 Nov 2010	263 days
90076	9 Mar 2010	90	112	106	111	98	99	101	11	3	244	141	55	17	114	137	23	457	1009	12 Nov 2010	249 days
Total		406	531	526	498	501	385	298	135	76	1035	835	340	118	435	484	109	2328	4338		

* Locations eliminated from analysis

Breeding areas

CLS ARGOS locations revealed that Bar-headed Goose (ID 99073) arrived first in its breeding ground (Table 1, Fig. 11) in the Tibetan Plateau and moved within an area of 3,155 sq. km (Table 3, Fig. 11). Based on segregation pattern of 508 locations, this individual appeared to use three focal areas (Table 4, Fig. 11) to carry out its daily activities within its breeding area. The first focal area which was used in April, June and August was 509.45 sq. km (based on 56 ARGOS locations) and the second, that was used from April to June and also in September was 438.1 sq. km (based on 248 ARGOS locations) (Table 4). However, the third focal area of activity was 457.22 sq. km (194 locations), located on the edge of a large lake in Tibet, that was used from June 20 to August 18, 2010. This focal area of activity was perhaps used by the goose for breeding. The distance between these focal areas varied from 28 to 53 km (Table 4). The bird remained in its breeding range for nearly six months and its transmitter stopped functioning on September 20, 2010.

The Bar-headed Goose (ID 99076) arrived in its breeding range on April 13, 2010, and established itself in the northernmost part among the four geese (Fig. 13). It moved over an area of 10,866 sq. km based on 344 locations (Table 3). Within the extensive area marked on the basis of locations, it used two focal areas of 1,168 and 3,368 sq. km intensively (Table 4). During spring migration it travelled the maximum distance (1,305 km) among the four geese fitted with PTTs, travelling 109 km per day on an average (Table 1). The transmitter of this goose stopped functioning on November 12, 2010, when it was in its wintering ground.

The third Goose (ID 99072) arrived in its breeding range on April 15, 2010, around Zhari Namco area of the Tibetan Plateau near a large lake (Fig. 10) at 4,830 m above msl. It moved over an extensive area of 5,263 sq. km (based on 379 ARGOS locations) (Table 3) in its breeding range where it could be monitored for more than five months. Based on segregation of 379 locations within its breeding range, there were four focal areas of activity used intensively by the bird (Table 4). One of the four focal areas, used between June 21 and August 14, was 236.21 sq. km (Table 4) and most of the locations within this focal area were on the edge of a large water body, Zhari Namco. The Bar-headed Goose probably bred within this focal area. The last location of the bird in this cluster was on August 22, 2010 when it was still around this lake, possibly with its young ones. The transmitter ceased functioning on September 15, 2010.

Another focal area of activity of the same bird was used from April 15 to May 26, the remaining two from May 17 to 26 and April 15 to June 20. There was a clear overlap of dates among these focal areas of activity, which means that the goose used more than one focal area (cluster of locations) on the same day.

The Bar-headed Goose (ID 99075) was last to migrate from Sur Sarovar and reached an area between Tangra Umco and Zhari Namco in the Tibetan Plateau at 5,179 m above msl, on April 16, 2010. Based on 459 ARGOS locations, this individual ranged within an area of 13,932 sq. km after reaching its breeding ground in Tibet on April 16 and used three focal areas of activity within 95% Minimum Convex Polygon (Table 4, Fig. 12). Among all marked geese, ID 99075 was found to have spent the maximum time (222 days) in its breeding grounds, since the transmitter on this bird remained functional for the maximum period (263 days) (Tables 2, 3). It used one focal area (690.18 sq. km) from April 4 to May 3, 2010. The second focal area (2,214.68 sq. km) was used from May 4 to 27 at the edge of a lake and the goose probably used

Table 3: Winter, stopover and breeding ranges of PTT equipped Bar-headed Geese and the total distance travelled by them

Bird ID	Winter range* (No. of locations)	NoDWR after Deploying PTT's	Stopover range* (No. of locations)	Halt at stopover site	Range in Breeding areas* (No. of locations)	Total distance travelled in Wintering range (km)	Stopover range (km)	No. of days in breeding ground
99072	106.76 (121)	30	30.17 (19)	7 days	5,262.84 (379)	224.11	66.53	153
99073	48.65 (59)	16	65.18 (21)	4 days	3,154.68 (508)	115.24	89.85	170
99075	149.84 (117)	36	-	-	13,932 (459)	404.26	-	222
99076	124.37 (72)	23	297.4 (23)	8 days	10,866.77 (344)	255.23	202.79	213

*areas are in sq. km

NoDWR = No. of days at wintering range

Fig. 3: Winter range of the Bar-headed Goose (99072)

Fig. 4: Winter range of the Bar-headed Goose (99073)

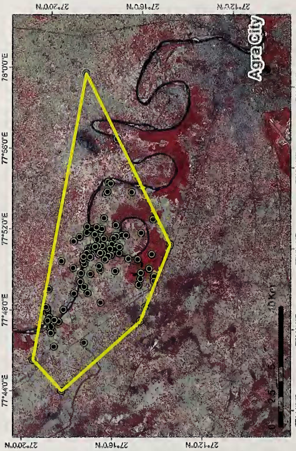

Fig. 5: Winter range of the Bar-headed Goose (99075)

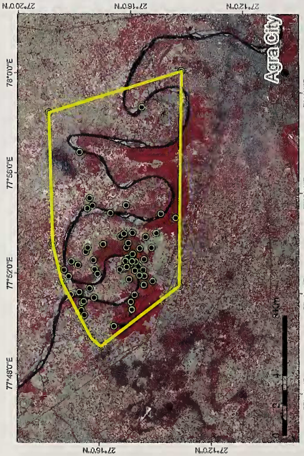

Fig. 6: Winter range of the Bar-headed Goose (99076)

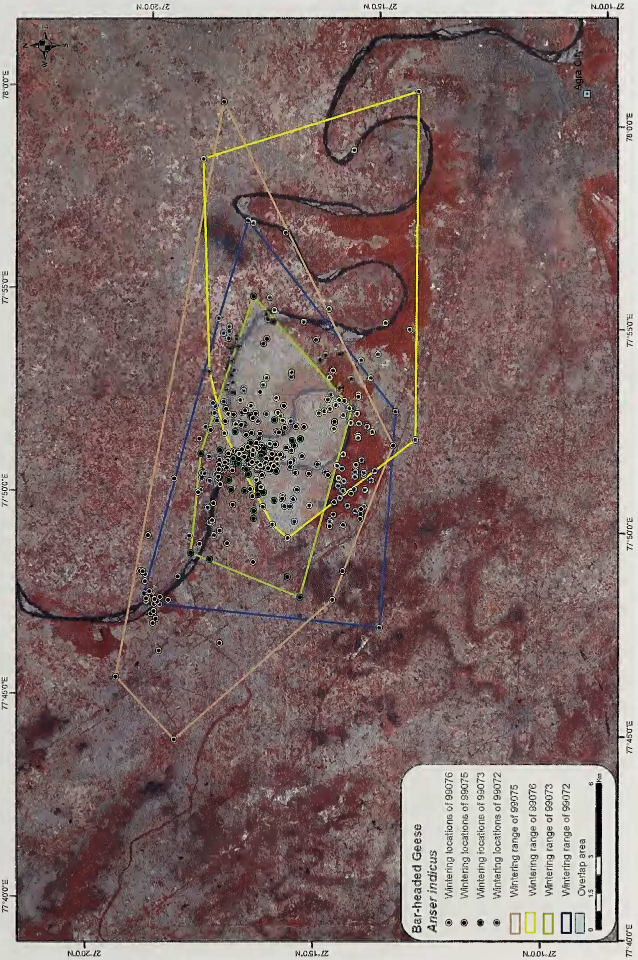

Fig. 7: Winter range of four Bar-headed Geese, showing range overlap

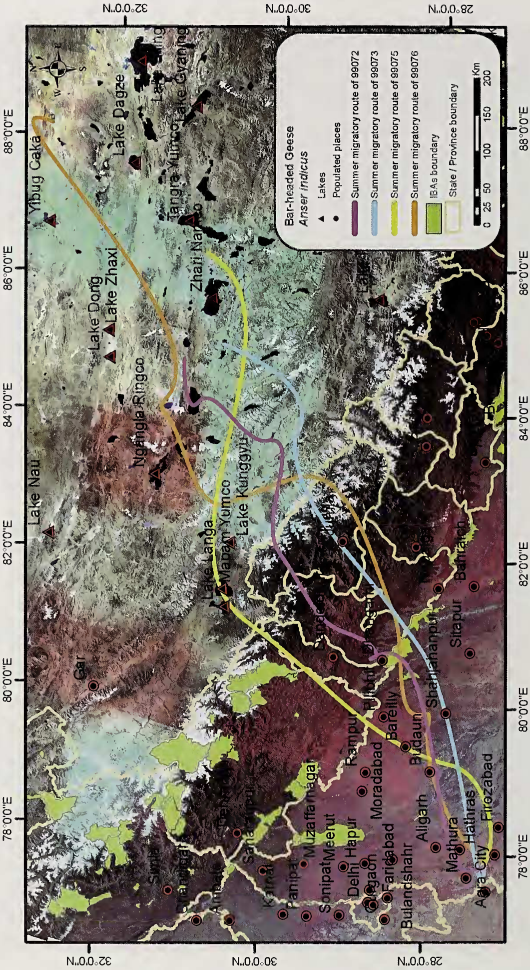

Fig. 8: Migratory routes of four Bar-headed Goose from Uttar Pradesh to Tibet (China)

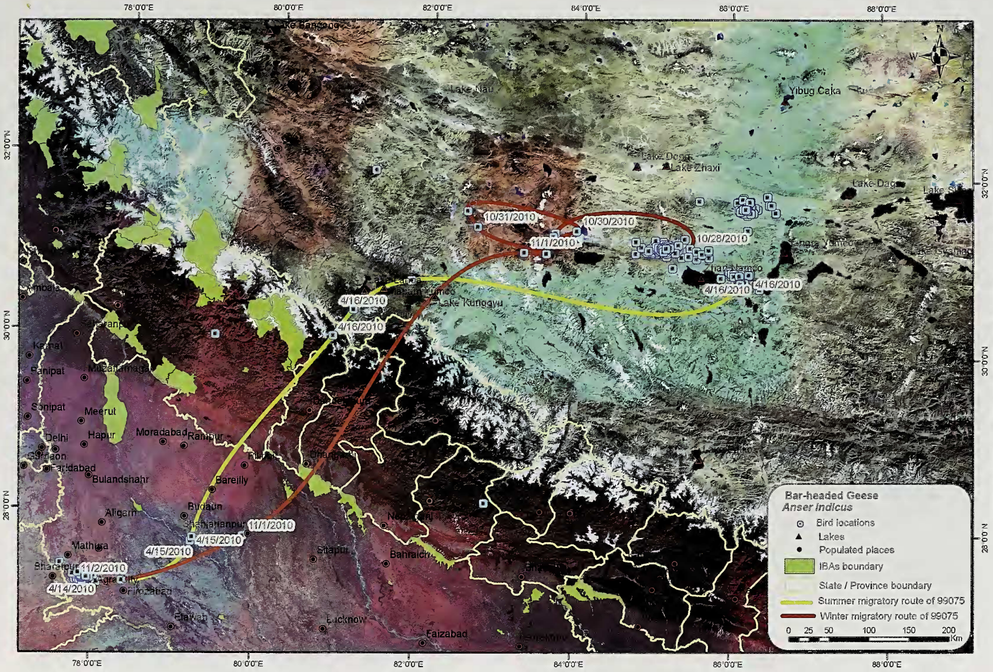

Fig. 9: Spring (yellow) and autumn (red) migratory route of the Bar-headed Goose (99075) from Yamuna catchment (U.P.) to Tibetan Plateau (China) and back

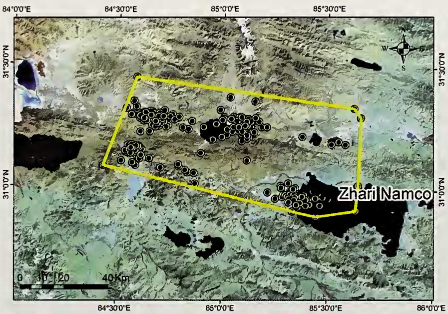

Fig. 10: Summer range of the Bar-headed Goose (99072)

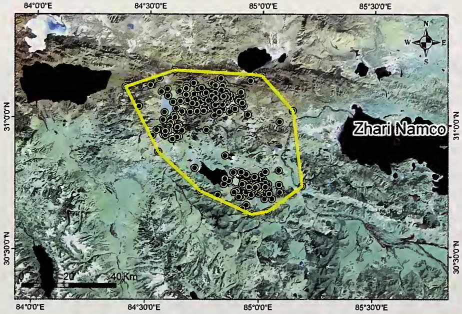

Fig. 11: Summer range of the Bar-headed Goose (99073)

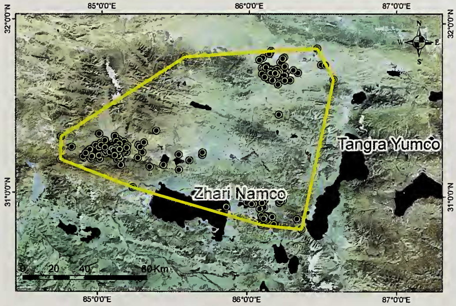

Fig. 12: Summer range of the Bar-headed Goose (99075)

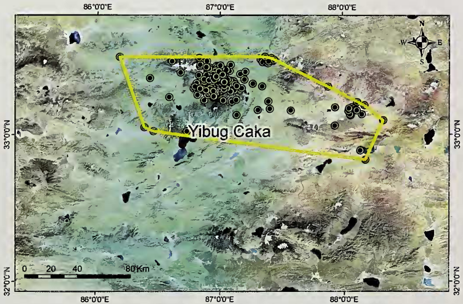

Fig. 13: Summer range of the Bar-headed Goose (99076)

Summer locations **Minimum Convex Polygon (95%)**

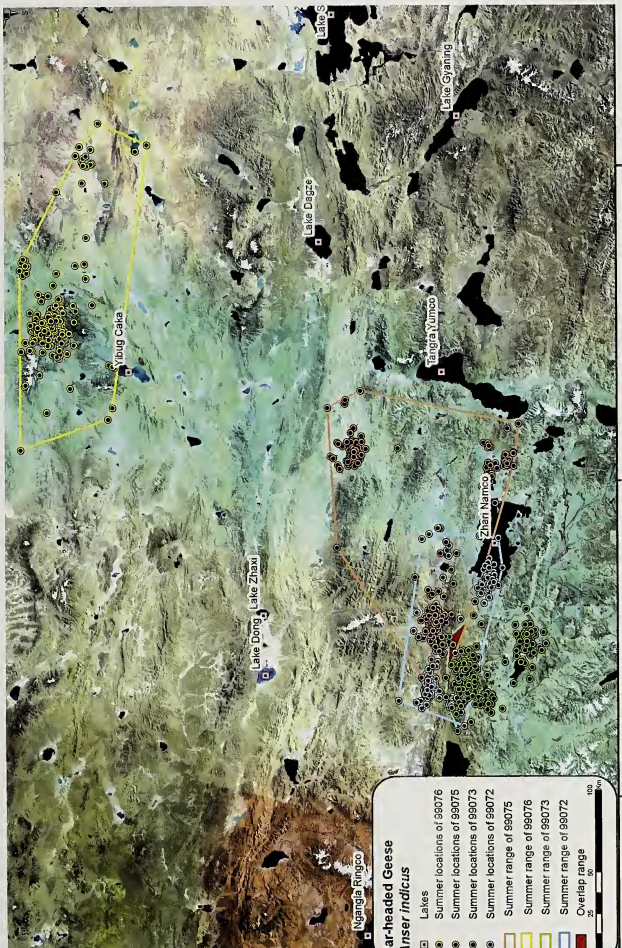

Fig. 14: Summer ranges of the four Bar-headed Geese in the Tibetan Plateau showing range overlap

Table 4: Focal areas of use within the breeding range of the geese on Tibetan Plateau

Bird ID	Focal areas of activity in breeding range				Distance between focal areas of activity (In km)				
	Focal area 1 (in sq. km)	Focal area 2 (in sq. km)	Focal area 3 (sq. km)	Focal area 4 (in sq. km)	Focal area 1 & 2	Focal area 2 & 3	Focal area 3 & 1	Focal area 3 & 4	Focal area 4 & 1
99072	75.19	389.9	253.25	236.21	19.48	36.66	49.32	45.95	78.34
99073	509.45	438.1	457.22	-	27.71	41.99	53.09	-	-
99075	690.18	2214.68	852.21	-	96.46	122.58	95.16	-	-
99076	1168.32	3368.11	-	-	100.69	-	-	-	-

it for breeding. Based on spatio-temporal segregation of ARGOS locations, the third focal area of activity (852 21 sq. km, Table 4) was used from August 28 to September 30, when it started moving towards its wintering range in India. This individual returned to its wintering ground on November 2, 2010.

The overlap area between 99075-99072 and 99073-99072 was 2,980 and 996 sq. km respectively. However, the total overlap area among 99075-99072-99073 was only 123 sq. km (Fig. 14).

DISCUSSION

Our study reconfirms that satellite-tracking is effective in studying the migratory movement of birds, and can be used for the identification of unknown migration routes, stopover and breeding sites. Here, we have provided a comprehensive description of migration from its origin, through wintering and breeding season movements of the Bar-headed Goose.

The four geese used the same migration route across India, Nepal and the Tibetan Plateau but their stopover sites differed from each other. We found that all four marked geese flew to breeding grounds located on the Tibetan Plateau. Similar migration routes have been reported for Bar-headed Goose in an earlier study (Javed *et al.* 2000). Geese are well known for flying across the Himalaya (Swan 1970; Javed *et al.* 2000), and adapted for flying at high altitude (Faraci *et al.* 1984, 1985; Ward *et al.* 2002; Scott and Milsom 2007). It has been reported that this species occupies a large range, but the possibility of range destruction is also reported due to global warming, changes in agriculture patterns and loss of wetland habitat at wintering ground.

Previous study on Goose migration reported that the geese captured in the wintering ground of India-Nepal migrated up to a distance of 500-800 km and ascended 4,500 m above msl to reach their breeding ground on the Tibetan Plateau whereas geese captured in China were reported to breed at 3,200 m above msl. However, Geese captured at Mongolia demonstrated leapfrog migration – i.e., they flew over another sub-population migrating from their wintering grounds in the Indian subcontinent to their breeding grounds in Mongolia (Takekawa *et al.* 2009). Our result indicates that geese captured at wintering areas in Uttar Pradesh, India, migrated from 877 to 1,305 km from their wintering areas on the Indian subcontinent to breeding grounds on the Tibetan Plateau and ascended quickly 4,790-5,520 m above msl (Fig. 2).

Koppen *et al.* (2010) reported that the four geese marked in Kyrgyzstan followed different routes leading to their wintering ground in India, Pakistan and Uzbekistan. However, in our study all the four geese captured in a sanctuary followed the same migration route to their breeding ground on the Tibetan Plateau.

Our study demonstrated that the geese also use areas outside Sur Sarovar Sanctuary that are currently unprotected. Therefore, providing protection outside the protected area is necessary for the long-term conservation of the Bar-headed Goose.

More long-term satellite tracking studies of the Bar-headed Goose from its wintering ground to breeding ground would provide the much needed migratory data such as different migratory routes, stopover sites, more specific breeding/summer sites, and threats that these migrants face. More detailed information is necessary also to find out the role of this and other migrant birds in the transmission of bird flu. This two-year study is a pilot effort, and the results suggest the need for further satellite tracking efforts to help expand our basic knowledge and understanding of these long distance migrants.

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